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# PATENT APPLICATION

## “ THERMAL SWITCH CONTAINING TEMPERATURE SENSOR ”

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## THERMAL SWITCH CONTAINING TEMPERATURE SENSOR

This application claims the benefit of U.S. Provisional Application Serial No. 60/237,874, filed in the names of Byron G. Scott and George D. Davis on October 4, 2000, the complete disclosure of which is incorporated herein by reference.

### FIELD OF THE INVENTION

The present invention is directed to temperature sensors and, more particularly, to snap-action thermal switches and electrical temperature sensors.

### BACKGROUND OF THE INVENTION

Snap-action thermal switches are utilized in a number of satellite applications, such as temperature control of batteries and hydrazine lines, and for overheat detection of mechanical devices such as motors and bearings. Current snap-action thermal switch designs typically provide open and closed functions only, whereby temperature data is available only at the instant the thermal switch operates. Current practice thus necessitates hard wiring of additional temperature sensors to sense a range of temperatures. These additional temperature sensors are typically installed in systems as subsystems that stand apart from the snap-action thermal switch systems that provide overheat protection, and thus increase overall system complexity and weight. Such additional temperature sensor subsystems are typically less reliable than a snap-action thermal switch. Overall system reliability is generally degraded when such additional temperature sensor subsystems are relied upon.

### SUMMARY OF THE INVENTION

The present invention overcomes the limitations of the prior art by providing a multiple output thermal detection and protection device that is capable of providing an output signal representative of the temperature sensed by the device, and further providing a

positive output signal representative of the sensed temperature reaching a predetermined set point temperature.

The invention is embodied, for example, in a first two-terminal device having first and second terminals extending through and to both sides of a substantially planar header, the terminals being electrically isolated from the header. The first two-terminal device also includes a first stationary contact fixed adjacent to one end of the first terminal; a second contact fixed adjacent to one end of the second terminal and being movable between a first position spaced away from the first stationary contact in an open circuit structure and a second position in contact with the first stationary contact in a closed circuit structure; an upright tubular spacer fixed to and projecting from the header and surrounding the first and second contacts and the portions of the first and second terminals adjacent to the contacts; a housing fixed to the header and enclosing all of the spacer, the first and second contacts, and the portions of the first and second terminals adjacent to the contacts, the housing also extending beyond the spacer and cooperating with the spacer to form an annular space therebetween spaced away from the contacts; a bi-metallic disc actuator captured within the annular space and being responsive to a sensed temperature of a predetermined set point to change state between a concave and a convex relationship to the electrical contacts, such that the disc actuator spaces the movable contact away from the stationary contact when in the concave relationship and the disc actuator permits the movable contact to contact the stationary contact when in the convex relationship; and an electrical temperature sensor sharing the first and second terminals in common with the respective first and second contacts and being structured to provide an output on one of the first and second terminals that is representative of the sensed temperature.

According to one aspect of the first embodiment of the invention, the disc actuator is structured to be in the concave relationship to the electrical contacts when the sensed temperature is below the predetermined sensed temperature, such that the circuit formed by the first and second contacts is open with the movable contact spaced away from the fixed contact, and the output of the electrical temperature sensor is available on the first and second terminals.

According to another aspect of the first embodiment of the invention, the electrical temperature sensor is one of a resistance temperature detector (RTD), a platinum

resistance thermal device (PRTD), a thermistor, a thermocouple, and a monolithic silicon temperature transducer.

The invention is also embodied, for example, in a three-terminal multiple output thermal detection and protection device having the output of the electrical temperature sensor is available whether the circuit formed by the first and second contacts is open or closed. Accordingly, the invention embodied as a three-terminal multiple output thermal detection and protection device includes: first, second and third terminals extending through and on either side of a substantially planar header, the three terminals being electrically isolated from the header and from one another; a first stationary contact fixed adjacent to one end of the first terminal; a second contact fixed adjacent to one end of the second terminal and being movable between a first position spaced away from the first stationary contact in an open circuit structure and a second position in contact with the first stationary contact in a closed circuit structure; an upright tubular spacer affixed to and projecting from the one side of the header and surrounding the first and second contacts, the portions of the first and second terminals adjacent to the contacts, and the third terminal; a housing enclosing the spacer, the first and second contacts, the portions of the first and second terminals adjacent to the contacts, and the third terminal, the housing extending beyond the spacer and cooperating with the spacer to form a space therebetween spaced away from the contacts; a bi-metallic disc actuator captured within the space between the spacer and the housing and being responsive to a sensed temperature at or near a predetermined set point for changing state between a first pressing upon and a second spaced away relationship to the movable electrical contact, such that the disc actuator spaces the movable contact away from the stationary contact when in the first pressing upon relationship and the disc actuator permits the movable to move into contact with the stationary contact when in the second spaced away relationship; and an electrical temperature sensor sharing one of the first and second terminals in common with the respective first and second contacts and being coupled to the third terminal for providing an output signal representative of the sensed temperature.

According to one aspect of the three-terminal embodiment of the present invention, the disc actuator is structured to be in either of the first pressing upon relationship

and the second spaced away relationship to the electrical contacts when the sensed temperature is below the predetermined sensed temperature.

According to still other aspects of the invention, the snap-action thermal switch is embodied as four-terminal and five-terminal switches.

5 According to another aspect of the three-terminal embodiment of the present invention, the electrical temperature sensor is one of a resistance temperature detector (RTD), a platinum resistance thermal device (PRTD), a thermistor, a thermocouple, and a monolithic silicon temperature transducer.

The invention also provides methods of accomplishing the same.

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#### BRIEF DESCRIPTION OF THE DRAWINGS

The foregoing aspects and many of the attendant advantages of this invention will become more readily appreciated as the same becomes better understood by reference to the following detailed description, when taken in conjunction with the accompanying drawings, wherein:

15

Figures 1 is a top plan view of the present invention embodied as a snap-action thermal switch;

Figure 2 is a cross-sectional view of the snap-action thermal switch of the present invention embodied as shown in Figure 1 with the contacts open;

20 Figure 3 is a cross-sectional view of the snap-action thermal switch of the present invention embodied as shown in Figure 1 with the contacts closed;

Figure 4 is a top plan view of one alternative embodiment of the present invention embodied as a snap-action thermal switch having an externally mounted electrical temperature sensor;

25 Figure 5 is a side view of the snap-action thermal switch of the present invention embodied as shown in Figure 4;

Figure 6 is a top plan view of another alternative embodiment of the present invention embodied as a snap-action thermal switch having an externally mounted electrical temperature sensor;

30 Figure 7 is a side view of the snap-action thermal switch of the present invention embodied as shown in Figure 6;

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Figure 8 is a top plan view of the present invention embodied as a snap-action thermal switch having a third terminal;

Figure 9 is a side view of the snap-action thermal switch of the present invention embodied as shown in Figure 8;

5                Figure 10A is one exemplary electrical schematic of the circuit formed by the three-terminal thermal switch of the invention, as embodied in Figures 8 and 9 and employing a RTD, PRTD, a thermistor, a thermocouple, or another suitable equivalent conventional electrical temperature sensor;

10              Figure 10B is another exemplary electrical schematic of the circuit formed by the three-terminal thermal switch of the invention, as embodied in Figures 8 and 9, wherein the electrical temperature sensor is embodied as a high precision temperature monitoring device of a type of high-reliability, two-terminal, monolithic silicon transducer having a linear temperature output over a wide range of temperatures;

15              Figure 11A is a top plan view of the a high precision temperature monitoring device utilized in the embodiment of Figure 10B;

Figure 11B is a side view of the high precision temperature monitoring device as shown in Figure 11A;

Figure 12 is a top plan view of the invention embodied as a four-terminal thermal switch;

20              Figure 13 is a side view of the invention embodied as a four-terminal thermal switch;

Figure 14 illustrates a first circuit for use with the embodiment of the four-terminal thermal switch of the invention, as shown in Figures 12 and 13;

25              Figure 15 illustrates a second circuit for use with the embodiment of the four-terminal thermal switch of the invention, as shown in Figures 12 and 13;

Figure 16 is a top plan view of the invention embodied as a five-terminal thermal switch;

Figure 17 is a side view of the invention embodied as a five-terminal thermal switch; and

30              Figure 18 illustrates a circuit that is compatible with the embodiment of the invention as described above and shown in Figures 16 and 17.

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## DETAILED DESCRIPTION OF PREFERRED EMBODIMENT

In the Figures, like numerals indicate like elements.

The present invention is a thermal protection device that provides temperature monitoring capability in combination with a normally open, snap-action thermal switch until  
5 the switch changes state from open to closed. This temperature monitoring capability in combination with a snap-action thermal switch provides several advantages over typical thermal protection devices. For example, additional wiring for a separate switch monitoring circuit which includes the device is eliminated, which reduces circuit complexity and increases system reliability. Separate mounting of the temperature sensor from the thermal  
10 switch is eliminated, which reduces the amount of space required by the monitoring and protection system. Meanwhile, the temperature monitoring capability in combination with a normally open, snap-action provides more accurate monitoring system temperature while providing reliable overheat protection.

Figure 1 is a top plan view and Figure 2 is a cross-sectional view of the  
15 present invention embodied as a snap-action thermal switch 10 having an internal electrical temperature sensor 12. The thermal switch 10 includes a pair of electrical contacts 14, 16 that are mounted on the ends of a pair of spaced-apart, conductive terminal posts 20 and 22. The electrical contacts 14, 16 are moveable relative to one another between an open and a closed state under the control of a thermally-responsive actuator 18. According to one  
20 embodiment of the invention, the thermally-responsive actuator 18 is a well-known snap-action bi-metallic disc that inverts with a snap-action as a function of a predetermined temperature between two bi-stable oppositely concave and convex states. In a first state, the bi-metallic disc actuator 18 is convex relative to the relatively moveable electrical contacts 14, 16, whereby the electrical contacts 14, 16 are moved apart such that they form an open  
25 circuit. In a second state, the bi-metallic disc actuator 18 is concave relative to the relatively moveable electrical contacts 14, 16, whereby the electrical contacts 14, 16 are moved together such that they form a closed circuit.

As illustrated in Figures 1 and 2, the thermal switch 10 includes the two terminal posts 20, 22 mounted in a header 24 such that they are electrically isolated from one  
30 another. For example, terminal posts 20, 22 are mounted in the header 24 using a glass or epoxy electrical isolator 26 (shown in Figure 1).

As shown in Figure 2, the contact 14 is fixed on the lower end of one terminal post 20. The contact 16 is moveable on the end of a carrier 28 in the form of an armature spring, which is fixed in a cantilever fashion to the lower end of the other terminal post 22. The electrical contacts 14, 16 thus provide an electrically conductive path between the terminal posts 20, 22. Upward pivoting of the armature spring 28 moves the movable contact 16 out of engagement with the fixed contact 14, whereby an open circuit is created. Downward pivoting of the armature spring 28 moves the movable contact 16 into engagement with the fixed contact 14, whereby the terminal posts 20, 22 are shorted and the circuit is closed.

The movable contact 16 is controlled by the disc actuator 18, which is spaced away from the header 24 by a spacer ring 30 interfitted with a peripheral groove 32. A cylindrical case 34 fits over the spacer ring 30, thereby enclosing the terminal posts 20, 22, the electrical contacts 14, 16, and the disc actuator 18. The case 34 includes a base 36 with a pair of annular steps or lands 38 and 40 around the interior thereof and spaced above the base. The lower edge of the spacer ring 30 abuts the upper case land 40. The peripheral edge of the disc actuator 18 is captured within an annular groove created between the lower end of the spacer ring 30 and the lower case land 38.

As shown in Figure 2, while the thermal switch 10 is maintained below a predetermined overheat temperature, the disc actuator 18 is maintained in a concave relationship to the electrical contacts 14, 16. The concave disc actuator 18 pivots the armature spring 28 upwardly to separate the contacts 14, 16 through the intermediary of a striker pin 42 fixed to the armature spring 28. Separation of the contacts 14 and 16 creates a normally open circuit condition.

The electrical temperature sensor 12 is implemented as any of a resistance thermal device (RTD), a platinum resistance thermal device (PRTD), a thermistor, a thermocouple, or another suitable equivalent conventional electrical temperature sensor 12, and is mounted to the interior of the thermal switch 10 and electrically connected to the two terminal posts 20, 22. For example, the electrical temperature sensor 12 is bonded to an inner wall surface of the spacer ring 30 using a bonding agent 44, such as an epoxy. The bonding agent 44 is optionally a thermally conductive epoxy, such as a silver or aluminum-filled epoxy, that effectively thermally couples the electrical temperature sensor

The thermal switch 10 is sealed to provide protection from physical damage. The thermal switch 10 is optionally hermetically sealed with a dry Nitrogen gas atmosphere having trace Helium gas to provide leak detection, thereby providing the internal electrical temperature sensor 12 with a clean, safe operating environment.

Figures 4-7 illustrate an alternate embodiment of the invention wherein the electrical temperature sensor 12 is installed on an exterior surface 52 of the thermal switch 10 and the lead wires 46, 48 are attached to exterior surfaces of the terminal posts 20, 22 of the thermal switch 10. The electrical temperature sensor 12 is, for example, bonded to the exterior surface 52 of the case 34, as shown in Figures 4-5. Alternatively, the electrical

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temperature sensor 12 is, for example, bonded to the exterior surface 54 of the header 24, as shown in Figures 6-7.

Another embodiment of the invention comprises installing a three-terminal temperature sensor to the thermal switch, and adding the third terminal to the thermal switch.

5 According to such an embodiment, the electrical temperature sensor 12 is thermally coupled to the internal surface of the thermal switch and is contained within the clean, dry, hermetic enclosure, such that separate packaging and wiring of temperature sensors are eliminated and the ultimate in savings and reliability for installations requiring thermal regulation, protection and monitoring are provided.

10 Figure 8 shows that a third terminal is added to the thermal switch 10 in the form of a third terminal post 56, which is electrically isolated from the header 24 by another one of the glass or epoxy electrical isolators 26.

Figure 9 shows that one of the lead wires 46 from the electrical temperature sensor 12 is electrically coupled to one of the terminal posts 20, 22. The other lead wire 48  
15 from the electrical temperature sensor 12 is electrically coupled to the third terminal post 56. For example, the lead wires 46, 48 are spot welded to an outer surface of the corresponding terminal post 20 or 22 and 56. The output of the internal electrical temperature sensor 12 is available on one of the terminal posts 20 or 22 and the third terminal post 56, whether the electrical contacts 14, 16 are open or closed. When practiced using the embodiment shown  
20 in Figures 8 and 9, the thermal switch 10 of the invention is used to independently monitor the actual temperature of the device while providing positive overheat protection.

Figure 10A is an exemplary electrical schematic of the circuit formed by the thermal switch 10, as embodied in Figures 8 and 9, and employing a RTD, a PRTD, a thermistor, a thermocouple, or another suitable equivalent electrical temperature sensor 12.

25 Figure 10B is another exemplary electrical schematic of the circuit formed by the thermal switch 10, as embodied in Figures 8 and 9, wherein the electrical temperature sensor 12 is embodied as a high precision temperature monitoring device of a type of high-reliability, two-terminal, monolithic silicon temperature transducer having a substantially linear temperature output over a wide range of temperatures.

30 Figures 11A and 11B are top and side view, respectively, that illustrate one example of such a temperature monitoring device 12, which is the model AD590 flat

package, two-terminal temperature transducer microchip available commercially from Analog Devices, Norwood, MA (vendor CAGE number 24355).

The invention is not limited to the type of snap-action thermal switch 10 that is shown in Figures 1-9. Rather, the invention is optionally practiced using any normally  
5 open, positive close thermal indication device.

The AD590 device 12 shown in top view in Figure 11A and in side view in Figure 11B is a two-terminal integrated circuit temperature transducer that produces an output current proportional to absolute temperature. For supply voltages between +4 V and +30 V, the device acts as a high impedance, constant current regulator passing 1  $\mu\text{A/K}$ .  
10 Thin-film resistor portions (not shown) of the AD590 microchip are laser trimmed to calibrate the device to 298.2  $\mu\text{A}$  output at 298.2K (+25°C).

The AD590 device can be used in any temperature sensing application below about +150°C in which conventional electrical temperature sensors are currently employed. The inherent low cost of a monolithic integrated circuit combined with the elimination of  
15 support circuitry makes the AD590 device an attractive alternative for other temperature measurement devices 12 in the practice of the present invention. Linearization circuitry, precision voltage amplifiers, resistance measuring circuitry and cold junction compensation are not needed in applying the AD590 device.

The AD590 device is known to be particularly useful in remote sensing  
20 applications, such as the present invention. The AD590 device is insensitive to voltage drops over long lines due to its high impedance current output. Any well insulated twisted lead wire pair is sufficient for operation hundreds of feet from the receiving circuitry. The output characteristics also make the AD590 device easy to multiplex: the current can be switched by a CMOS multiplexer or the supply voltage can be switched by a logic gate  
25 output.

Figure 12 is a top plan view of the invention embodied as a four-terminal thermal switch 10, and Figure 13 is a side view. The four-terminal embodiment provides for compensation of the resistance in the wiring harness when accurate thermal measurement data is desired using the RTD, PRTD, thermistor, thermocouple, or other suitable equivalent  
30 conventional electrical temperature sensor 12. One of the two terminals of the temperature sensor 12 is coupled via one lead wire 46 to one of the two switch terminal posts 20, 22, as

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described above. The other terminal of the temperature sensor 12 is coupled via the other lead wire 48 to the third terminal post 56, and is further coupled to a fourth terminal post 58 by a third lead wire 60.

When practiced using the embodiment shown in Figures 12 and 13, the thermal switch 10 of the invention is used to monitor the actual temperature of the device while providing positive overhear protection. Furthermore, coupling the third lead wire 60 to the fourth terminal post 58 permits measurement of the resistance in the wiring harness so that compensation can be administered, thereby making more accurate the temperature measurement provided by the temperature sensor 12.

Figure 14 illustrates a circuit 62a that is compatible with the embodiment of the invention as described above and shown in Figures 12 and 13, wherein the temperature monitoring device 12 is embodied as the model AD590 described herein. The temperature monitoring device 12 is accessed via terminals T3 and T4.

Figure 15 illustrates a second circuit 62b that is also compatible with the embodiment of the invention as described above and shown in Figures 12 and 13. The temperature monitoring device 12 is embodied as the model AD590 described herein, and the temperature monitoring device 12 is accessed via terminals T3 and T4.

Figure 16 is a top plan view of the invention embodied as a five-terminal thermal switch 10, and Figure 17 is a side view. The five-terminal embodiment provides for compensation of the resistance in the wiring harness when accurate thermal measurement data is desired using the integral electrical temperature sensor 12 embodied as a RTD or PRTD.

Figure 18 illustrates a circuit 66 that is compatible with the embodiment of the invention as described above and shown in Figures 16 and 17. The five-terminal embodiment completely separates a circuit 68 of the snap-action portion of the thermal switch 10 from a circuit 70 having the integral temperature sensor 12 embodied as a RTD or PRTD. The electrical contacts 14, 16 of the snap-action thermal switch 10 are coupled to the first terminal posts 20 and 22. The lead wires 46, 48, and 60 are coupled to the respective second terminal posts 58, 56, and 64, as shown in Figure 17.

When practiced using the embodiment shown in Figures 16 and 17, the thermal switch 10 of the invention is used to monitor the actual temperature of the device

completely independently of the positive overheat protection portion of the thermal switch  
10. Furthermore, coupling the third lead wire 60 to the fourth terminal post 58 permits  
measurement of the resistance in the wiring harness so that compensation can be  
administered, thereby making more accurate the temperature measurement provided by the  
5 temperature sensor 12 embodied as a RTD or PRTD.

While the preferred embodiment of the invention has been illustrated and  
described, it will be appreciated that various changes can be made therein without departing  
from the spirit and scope of the invention.

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